Experimental Measurement of Motor Variables with Different Drone Propellers

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***Abstract*—This paper presents a comprehensive characterization of thrust and power dynamics in small unmanned aerial vehicle (UAV) propulsion systems. The thrust test bench is designed to measure the thrust that each motor can generate under different power levels and with various propellers. The purpose of this work is to determine the most suitable propeller for a given drone motor, considering that motor efficiency and response capability are decisive factors in the drone's overall performance. This work focuses on the thrust and current analysis of a brushless motor with seven different propeller options on the market. The results show that the propeller efficiency and thrust are influenced by the material used and the stiffness of the material, which varies according to the manufacturer. This research serves as a practical foundation for the selection and optimization of propeller and motors, promoting better-informed design choices across a wide range of UAV applications.**

***Index Terms*—thrust test bench, drone, propeller, brushless motor, Arduino, PowerBI**

I. Introduction

Test benches are an engineering tool adopted across various areas to obtain information regarding the performance of a system [1]. This information is often used to design power optimization strategies, economic alternatives, or simply as selection criteria [2]. Today, as shown in [3], test benches can be in conjunction with the paradigm of Industry 4.0, allowing the creation of digital solutions that aim to increase efficiency.

The main objective of test benches for drone motors is to measure the thrust that each motor can generate under different power levels and with various propellers. Through this methodology, it is possible to experiment with different components to understand the behavior of the brushless motor in terms of thrust and power consumption. This model allows for repeated and verifiable measurements that ultimately ensure proper performance.

Conducting a thrust test for drone motors is important because it determines the drone response when in operation. Studying this variable is essential for selecting propellers that enable better efficiency [4]- [5]. At present, few commercial test benches allow for the proposed research, and they tend to have high costs or to use devices that are not easily accessible. Some of the test benches available on the market have also been discontinued or are subject to patents that are not available to the public [6]. It is worth mentioning that the drone-building community is robust and supportive, which has resulted useful for this team. Rudimentary works such as those shown in [7] and [8] provide inexpensive and easy-to-build solutions that have been taken into account during the development of this project. However, the closeness of the community comes at the cost of formality, which renders the acquisition of specifics more difficult when it comes to market drone propellers.

A. Background and State of the Art

The implementation of test benches is a practice that has evolved in various industries and fields such as engineering, aviation, automation, and other technical disciplines. In the aerospace engineering domain at the University of Oklahoma, a test bench was designed and implemented to study the performance of propellers with different Reynolds numbers and varying pitches. The tests were iterated several times for 3 days to ensure the repeatability of the experiment. The results obtained by the researchers demonstrated that the Reynolds number does indeed affect the performance of the propeller [9].

In 2010, a group of researchers conducted high-precision tests on propellers for small aerial vehicles. The methodology involved designing 5 test benches to gather information on thrust, torque, and RPM. The results of the investigation revealed that the torque data collected with the test benches was not very accurate [10].

At EIA University, a test bench was constructed to characterize propellers using torque and thrust coefficients. This was achieved by measuring them through a set of calibrated masses and the thrust generated by the engine. Deformation data were obtained using strain gauges in a cell bar [5].

Test benches can also be designed and applied for complex studies. An example of this is their use in rocket propellers that test or simulate aerodynamic conditions of flight for an aircraft [11].

Concerning mechatronics and mechanical engineering, test benches are often used to emulate real-life conditions in a model, as do [12]- [13], which recreate mechanical loads (e.g., on-road conditions) to evaluate motor performance or to measure controlled motor behavior given certain control variables, as in the works [5]- [11]. This paper focuses on the latter, specifically the measurement of thrust and current for a given drone motor with varying propellers. Accordingly, the creation of a thrust test bench for a brushless motor by varying the propellers to find the optimal ones is proposed. For this project, propellers that were available at EIA University were used.

B. Types of Test Benches

There are various ways to set up a test bench and it often involves a creative process to obtain measurements of the variables under study. However, two well-known and easy-to-build methods are scale-based test benches and load cell-based test benches. The first method involves fixing the motor to a block with a weight much greater than the force the motor can generate. To ensure that it is static, the blades should also be positioned so that the air mass is directed upward. The weight-motor configuration should be placed on a scale that allows for taring, so the measured value corresponds to the thrust caused by the motor. With this technique, data collection is done manually as in [8].

With the second technique, a load cell is used, which is a sensor that measures the force or weight of an object using the Wheatstone bridge configuration. This sensor provides digital data that can be interpreted on a computer. The methodology for this technique requires more effort, but offers more freedom in the measured variables due to its precision. To set up this technique, a static and rigid vertical structure is necessary. An Arduino and an interface to interpret the information along with sensors to measure variables that may include but are not limited to current, voltage, and deformation, are also required [5]- [7].

II. Methodology

A. Materials

Assessing UAV motor performance requires a reliable thrust test bench. The following components were selected based on availability and cost:

- Arduino UNO R3
- ACS712ELCTR-30A-T current sensor
- TAL220 load cell
- HX711 amplifier module
- Xing-E 2207 1800kv motor
- Readytosky 30A ESC with 2A BEC
- CNHL 30C 2200mAh 3S LiPo battery

B. Design

Key measured variables were thrust (output) and current (input). Propeller specs, expressed as pitch:length (e.g., 50:30), were taken from the manufacturer. A detailed CAD model (Fig. 1) was created using Autodesk Inventor 2023, showing the spatial layout of components on the base. This blueprint ensured precise placement and optimal test bench functionality.

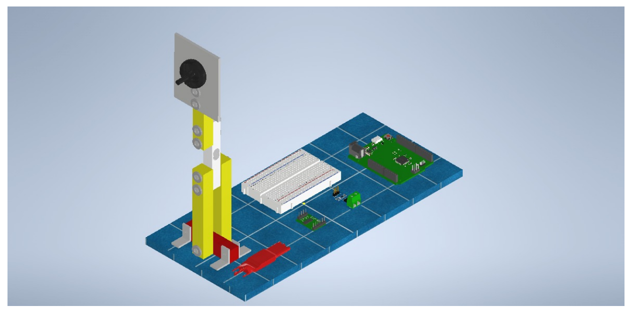


Fig. 1. Motor thrust test bench CAD design.

C. Hardware

After acquiring the components, wood and MDF parts were cut based on datasheets. The motor base (Fig. 2) was crafted with tight tolerances to secure the motor and fit into the cell bar assembly.

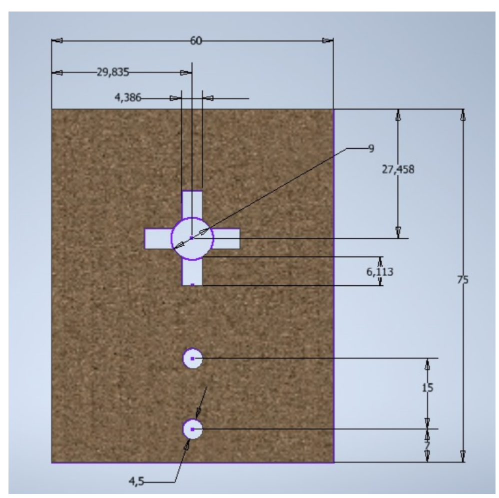


Fig. 2. MDF motor base CAD design. Measurements in mm.

The assembled bench (Fig. 3) followed manufacturer guidelines for wiring. A shared ground and 5V line powered all devices. The Arduino pin configuration was: A0 (current), pins 2 and 3 (HX711 CLK and DAT), and pin 9 (ESC PWM). These can be changed if the code is updated accordingly.

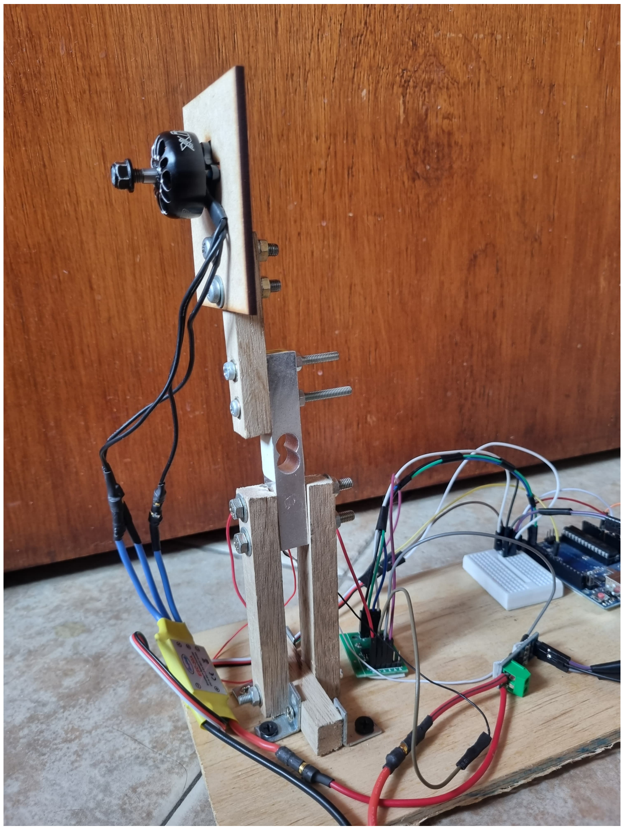


Fig. 3. Assembled motor thrust test bench

D. Software

Arduino code, written in the Arduino IDE, uses 'EEPROM.h', 'Servo.h', and 'HX711_ADC.h' (available at GitHub, see Section V, URL 1). The code reads sensor data, controls motor power using 'millis()', and sends results via serial in CSV format.

The step test is driven by the 'Tpotencia' variable (4000 ms), with faster power-downs to preserve battery life. Full details are in the 'Final.ino' file (MTTB repository, Section V, URL 2).

A second script, 'ArduinoPostgreSQL.py', handles serial communication and stores results in a local PostgreSQL database. Users must configure hostname, password, and database name. Output is in Spanish but can be adjusted.

The data format is: thrust, current, time, and propeller specs. Dependencies ('serial', 'psycopg2') must be installed with 'pip'. PostgreSQL must be installed and configured before running the script.

E. Data Collection

After setup, data collection followed this protocol:

1) Attach and check propeller orientation.
2) Connect battery to ESC.
3) Connect Arduino via USB.
4) Arduino starts automatically; run Python script manually.
5) Motor runs through its sequence.
6) Disconnect battery after motor stops.
7) Press Enter to store data.
8) Disconnect Arduino and verify data.
9) Remove propeller and prepare for next test.

This process was repeated for seven propellers: 50:30N, 50:43A, 50:43N, 50:45N, 50:43E, 50:43T, and 51:45R. Numbers refer to diameter (inches ÷ 10) and pitch (degrees); letters distinguish physical traits (e.g., color, material, stiffness).

Post-processing and visualization were performed in PowerBI (Section III), using line, scatter, and area charts to explore thrust-current and temporal trends.

III. Results and Discussion

After applying the methodology described in Section II and using Power BI software, the data obtained, were graphed to facilitate interpretation and analysis of the results. Fig. 4 shows the behavior of the Xing-E 2207 1880kv motor, the variables studied being time in milliseconds and thrust in grams. The 50:45N propeller exhibited the highest thrust, reaching a value of 368.98 grams.

The two presented graphs Fig. 4 and Fig. 5 offer a detailed view of the behavior of the Xing-E 2207 1880kv motor when used with two different propellers, 50:43T and 50:45N, in terms of thrust (g) over time (ms). This analysis is crucial for determining the most suitable propeller for a drone, considering that motor efficiency and response capability are decisive factors in the drone's overall performance.

A. Analysis of the 50:43T propeller

In this graph, a maximum thrust of 354.67 g and an average thrust of 160.68 g can be observed. The thrust curve shows a rapid increase in the first milliseconds, reaching its peak around 25 ms before starting to gradually decrease. This pattern indicates that the motor has a very fast response capability, reaching its maximum performance in a very short time. This characteristic is essential for drones that require an immediate response, such as racing drones or those used in applications that demand quick and precise maneuvers.

The average thrust of 160.68 g suggests that over a prolonged period, the motor can maintain a sustained thrust close to this value. This is important for the stability and control of the drone, especially in constant flight conditions. The ability to maintain constant thrust allows the drone to fly stably, which is crucial for applications such as aerial photography, where a smooth and controlled flight is needed.

B. Analysis of the 50:45N propeller

In contrast, this propeller shows a slightly higher maximum thrust, reaching 368.98 g, and an average thrust of 160.49 g. The shape of the curve is very similar to that of the 50:43T propeller, with a rapid increase in thrust reaching its peak also around 25 ms, followed by a gradual decrease. The similarity in the shape of the curves suggests that both propellers allow the motor to reach its maximum thrust in a similar time, but the 50:45N propeller offers slightly better performance in terms of maximum thrust.

The maximum thrust of 368.98 g is a notable advantage, especially in situations where higher thrust performance is required. This can be beneficial for drones that need to lift additional loads, such as heavier cameras or specialized sensors. Additionally, higher maximum thrust can improve the drone's ability to make quick ascents and overcome stronger air currents.

C. Detailed comparison and propeller selection

When comparing both graphs, it can be deduced that the 50:45N propeller provides higher maximum thrust compared to the 50:43T. This increase in maximum thrust can be beneficial in situations where higher thrust performance is required, although the difference in average thrust between both propellers is minimal. This suggests that although the 50:45N propeller has an advantage in maximum thrust, both propellers offer similar performance in normal operating conditions.

The choice of the most suitable propeller for a drone should be based on several key factors:

1) Type of drone and application: Racing drones, for example, benefit from propellers that provide quick response and high maximum thrust for agile maneuvers. On the other hand, aerial photography drones require propellers that offer smooth and stable flight with constant thrust.
2) Load capacity: If the drone needs to carry additional loads, such as heavy cameras or sensors, a propeller that offers higher maximum thrust, like the 50:45N, would be more suitable.
3) Flight duration: Average thrust is important for energy efficiency and flight duration. Propellers that offer good average thrust without consuming too much energy will help prolong the drone's flight time.
4) Flight conditions: In turbulent flight conditions or strong winds, a propeller with higher maximum thrust can offer better performance, helping the drone maintain its stability and direction.

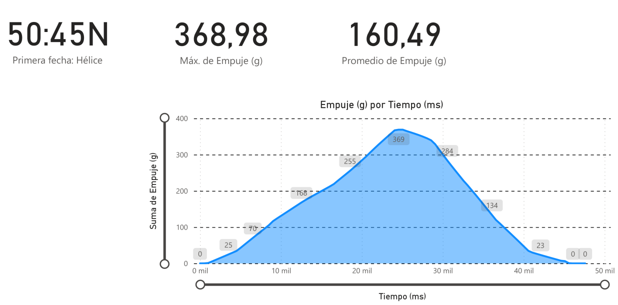


Fig. 4. Thrust versus time plot with the 50:45N propeller.

D. Influence of propeller design and material

Motor performance in terms of thrust is closely related to the design and material of the propellers. Different manufacturers may offer propellers with variations in design and materials used, which can significantly affect motor performance. For example, propellers made of lighter materials or with optimized aerodynamic profiles can improve thrust and motor efficiency.

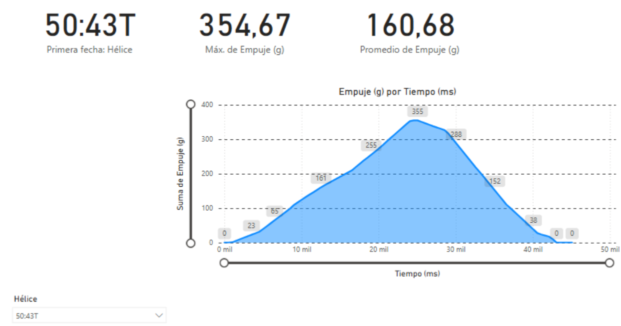


Fig. 5. Thrust versus time plot with the 50:43T propeller.

- Aerodynamic design: Propellers with advanced aerodynamic design can reduce air resistance, allowing for more efficient thrust. This not only improves maximum thrust but can also contribute to higher average thrust and longer flight duration.
- Materials used: Propellers made with light and strong materials, such as carbon fiber, can offer a better thrust-to-weight ratio. These materials are also more durable and can better withstand impacts and wear, which is crucial for drones operating in challenging environments.
- Balance and rigidity: Good balance and rigidity of the propeller are essential to reduce vibrations and improve flight stability. Vibrations can negatively affect the quality of aerial photography and the precision of the drone's sensors.

Both propellers, 50:43T and 50:45N, allow the Xing-E 2207 1880kv motor to reach its maximum performance at a similar time, but the 50:45N propeller offers a slightly higher maximum thrust. The choice between these two propellers will depend on the specific needs of the drone and its application.

For drones that require quick response and maneuverability, such as racing drones, both propellers may be suitable, but the 50:45N could offer a slight advantage in terms of maximum thrust. For applications that require stability and control, such as aerial photography, both propellers offer similar performance in terms of average thrust, so the choice could be based on other factors such as durability and energy efficiency. It is crucial to consider the design and material of the propeller, as these factors can have a significant impact on the drone's performance. Evaluating the available propeller options on the market and conducting practical tests can help determine the most suitable propeller for the drone's specific needs and application.

E. Current analysis

Throughout the research, it was observed that the motor performance in relation to thrust is influenced by the implemented propeller and the stiffness of the material from which it is made, which varies according to the manufacturer.

In Fig. 6, the behavior of the current about time is examined, revealing a step pattern in the curve. This phenomenon is attributed to the type of test conducted, which is implemented using steps that vary in magnitude over time as the current increases. The purpose of this procedure, known as a step test, is to induce changes in motor speed to collect data on thrust. Additionally, peaks are observed in the curve, indicating that when making rapid changes in current with the ESC, the motor cannot respond instantaneously, leading to the disturbance known as the Gibbs phenomenon, the explanation of which is beyond the scope of this paper.

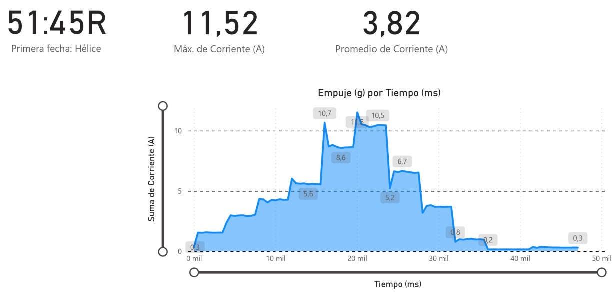
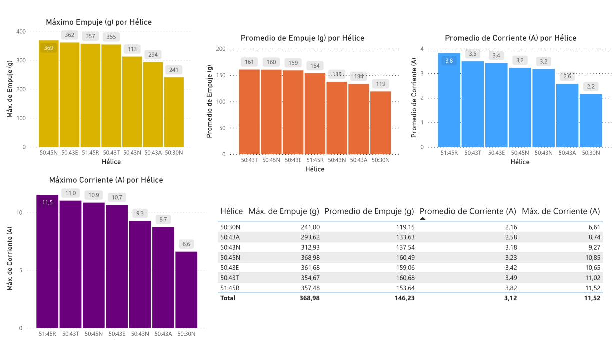


Fig. 6. Plot of current versus time with the 51:45R propeller.

When analyzing the maximum current over time and comparing all the results (see Fig. 7), the goal was to identify the propeller that exhibited the lowest current consumption. The propeller that yielded the best results was 50:30N. However, it is important to note that this propeller provided the lowest thrust of all, making it less suitable for achieving optimal motor performance. For this reason, and considering the maximum thrusts were achieved with the 50:45N and 50:43E propellers, the team considers these to be better suited for a low-budget drone design due to their high thrusts with arguably low current consumption.



Hélice	Máx. de Empuje (g)	Promedio de Empuje (g)	Promedio de Corriente (A)	Máx. de Corriente (A)
50:30N	241,00	119,15	2,16	6,61
50:43A	293,62	133,63	2,58	8,74
50:43N	312,93	137,54	3,18	9,27
50:45N	368,98	160,49	3,23	10,85
50:43E	361,68	159,06	3,42	10,65
50:43T	354,67	160,68	3,49	11,02
51:45R	357,48	153,64	3,82	11,52
Total	**368,98**	**146,23**	**3,12**	**11,52**

Fig. 7. Summary of all plots obtained with the different propellers used.

The Fig. 8 examines the relationship between current and thrust through a scatter plot. This analysis revealed it to be proportional, showing a tendency toward a straight line (linear relationship). This suggests that when the motor reaches its maximum thrust, the consumed current also reaches its highest recorded value.

All graphs of the results are available through the URL 3 in Section V.

IV. Conclusions

This study demonstrates the critical influence of propeller selection on the performance and efficiency of unmanned aerial vehicles (UAVs). The results highlight that propellers

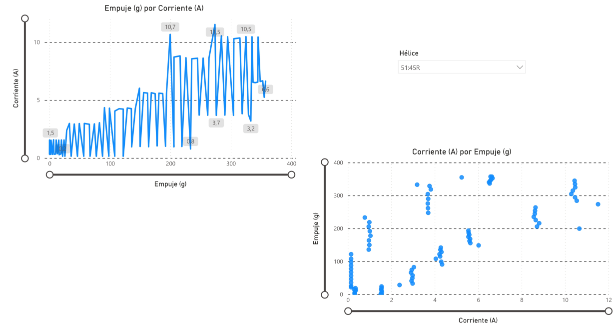


Fig. 8. Thrust and current graph with propeller 51:45R.

such as the 50:45N and 50:43E deliver high thrust with relatively low current consumption—an essential factor for enhancing flight autonomy and optimizing energy use, particularly in cost-sensitive or endurance-focused UAV designs.

The temporal analysis of current revealed step-like patterns, corresponding to controlled changes in motor speed during thrust data acquisition. Additionally, observed peaks in current curves, attributed to the Gibbs phenomenon, suggest that motors exhibit transient limitations when subjected to abrupt input changes. This behavior may compromise stability in dynamic flight scenarios and should be considered in control system design.

A strong linear correlation between thrust and current was established, confirming that higher thrust outputs demand proportionally greater electrical input. This insight is pivotal for correctly sizing Electronic Speed Controllers (ESCs), ensuring reliable motor operation within thermal and electrical limits.

Material properties and stiffness of the propellers also significantly affected performance. While stiffer blades can enhance thrust generation, they may lead to increased current consumption, presenting a trade-off between efficiency and responsiveness. Selecting appropriate materials should therefore align with mission-specific requirements—favoring stability and low power draw for tasks like aerial imaging, or prioritizing rapid response and high thrust for racing or agile operations.

In summary, this work provides a comprehensive characterization of thrust and power dynamics in UAV propulsion systems. The findings serve as a practical foundation for the selection and optimization of propellers and motors, promoting better-informed design choices across a wide range of UAV applications.

A. Future Work and Research Directions

The propeller efficiency and thrust analysis presented in this work has practical implications across various UAV applications, including emergency response, delivery logistics, precision agriculture, surveillance, and drone racing. High-thrust propellers (e.g., 50:43T) enhance maneuverability and response, while energy-efficient designs (e.g., 50:45N) extend flight duration and payload capabilities. These insights support the adaptation of UAV systems to specific operational demands, promoting targeted design optimization.

To further evaluate and expand the functionality of the thrust test bench, the following experiments are proposed:

- **Sweep/Ramp Test:** Continuously vary thrust to observe system response across the full operating range.
- **Endurance Test:** Assess performance and thermal behavior under prolonged operation.
- **Constant Thrust Test (Closed-Loop):** Evaluate control precision in maintaining fixed thrust amid external disturbances.
- **Settling Time Test:** Quantify response time to reach 90% of target thrust after step inputs.
- **Flight Replay Test:** Use recorded flight data to replicate real-world scenarios on the bench.
- **Sinusoidal and Chirp Tests:** Characterize frequency response and system stability under oscillatory and time-varying inputs.

These tests will contribute to a more robust performance characterization and enable further development of UAV propulsion systems for diverse use cases.

V. Supplementary Materials

1) The external library used to read the signal from the HX711 ADC sensor is available in the HX711_ADC GitHub repository using the following URL: https://github.com/olkal/HX711_ADC.
2) The code utilized in this project is available in the MTTB GitHub repository using the following URL: https://github.com/santy-estrada/MTTB.
3) The graphs used to support the findings of this study have been deposited in the PowerBI repository Data report or using the following link: https://app.powerbi.com/view?r=eyJrIjoiMjNhNjlmNDAtMmIxYS00NWJjLWJlZGEtODc4Y2ZkNjQxMWE3IiwidCI6ImEyMWY0YzI3LTMzZTUtNGNhZC1hMWZmLTYxNjdiZDlmOWE0NSIsImMiOjR9.

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